An assessment of the technological needs for a competence-based, computer-assisted course in Electrical Engineering

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***Abstract*--This paper reports on ongoing work at our college concerning the integration of educational content developing methodologies and existing simulation (PSPICE) and symbolic manipulation tools (MATLAB) for computer-assisted teaching in the context of Electrical engineering education. We have focused on building a platform that is capable of offering an extremely complex kind of discursive educative interaction enabling both teachers and students to agree on their goals, describe their conceptions about a particular knowledge domain and act on a model of it through simulation.**

***Index terms*— computer-assisted learning, engineering skills learning, educational systems and tools integration, educational content development methodologies.**

I. INTRODUCTION

There are founded hopes that computers and knowledge management will bring about the much wished-for revolution in educational techniques: the aim is to challenge the pervasiveness of lectures as the main teaching mechanism, - and the supporting notes- and book-based schemes – by means of computer-enabled content (possible multimedia)[3]. The problem still remains the costly and static nature of educational content in computer form.

We are testing a methodology to develop educational content on the basis of modular competence development [1], so that content can be reused from one course to another, and knowledge management techniques applied to it. Briefly, the methodology starts with a top-down hierarchical analysis of learning competences; once reached a basic specification level, it allows to design bottom-up educational units which have a clear structure: introduction, new material, training exercises and recapitulation. These basic units are then structured naturally as a graph which makes clear the preconditions between competences so as to suggest a navigation order – not necessarily linear – of the domain. [2] offers a more in-depth presentation of the subject.

Questions arise as to the applicability of the methodology when the competences and skills to be developed involve technical abilities or traditional problem-solving mathematical skills. Specifically, it is debatable whether a teaching-enabled information system with only a textual interface to the competence graph could be of any use in developing the operational skills required for such competences. Lecturers not only speak or write in the blackboard, but draw visual (for example, circuits or graphs) or algebraic specifications of knowledge (equations) as well. More to the purpose, they intelligently (most of the time) manipulate such specifications and formalisations accurately.

On the other hand, some education professionals demand a new, more interactive educational process [3], which imposes new requisites in any type of computer-supported system that propounds at more interactive, media-richer devices to convey instruction. This interactivity concerns mainly the do-to-learn aspect, the elicitation of student conceptions and teacher feedback on these conceptions.

On perusing an analysis of teaching media ([3], pp. 107-178), in an engineering context, we claim that adequate complements of discursive content for engineering subjects (either lineal text or hypertext) would be:

- a simulation tool allowing the user to interact with a model of the domain of knowledge to receive feedback directly from his/her actions;
- a symbolic mathematics tool both to be able to describe teacher and student conceptions of the domain knowledge and to manipulate them in a familiar form (calculus), thus expanding the possibilities of model elicitation from both students and teachers.

In the following, we first describe the requisites of the content development technology, set out to describe part of a standard subject in Electrical Engineering, and then describe the process of complementing the normal learning tool, a browser, with other, more specialised tools. Finally, we extract some conclusions on the experience and then propose further work to do.

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II. INSTRUCTIONAL CONTENT DEVELOPMENT

A. A methodology for top-down guided, bottom-up developed educational content.

A number of methodologies have been proposed for the development of educational content. Out of these, we have selected one based in the concept of "competence", which is an embodiment of the skill a student must acquire/prove able at in the process of learning ([1], pp. 15-27), a contextualised, testable learning objective.

The process of defining competences starts with an analysis of the motivation to develop a course, then proceeds stating the learning goals and performing a functional analysis in a top-down manner to split every objective into subobjectives attainable during one "study session". A study session is the training allowed for a typical student and each course unit may span one or more such sessions. In fig. 1 the overall layout of a study session is shown with a particular competence zoomed out until the level where it can no longer be expanded. Afterwards, bottom-up synthesis of materials proceeds from the creation of study session materials, through the aggregation of sessions until chapter (or subject) completion, following the scheme set by hierarchical aggregation.

Thus, every basic study session is structured into:

- an *advance organizer*, that helps introduce and motivate the competence;
- the *contents* of the session which develops the competence;
- a *summary* where a statement of the objectives and self-assessment is carried out and,
- optionally, some *reinforcement practices, examples, etc*., in case self-assessment fails to be satisfactory.

Study unit aggregates are also given advance organizers and summaries, but self-assessment is more difficult for these aggregate units as it involves the *integration of competences*. The process is finished when the whole chapter (subject) is assigned an advance organizer, a summary and, possibly, self-assessment activities.

B. An analysis of the special requirements for developing contents in an engineering subject.

Unfortunately, no provision is made in the methodology described above for the specification of the features of the contents of each session. In particular, no distinction is made between two very different types of knowledge pertaining to the teaching of engineering subjects: declarative knowledge aimed at increasing understanding and operational knowledge aimed at increasing skills, although the interplay of both is to be hoped for.

Previously, we synthesized a methodology for developing content specifically targeted at computer-assisted education greatly inspired in the one described beforehand but taking into consideration a dual feature of competences [2]:

- they include declarative knowledge in the form of "concepts" which have to be acquired, and
- they promote operational knowledge in the guise of specialized skills relating to the concepts above, so called "dexterities".

This suggests a dual approach to learning the learn-to-do approach - in the sense of first learning concepts *then* practicing them -, and the do-to-learn approach – first get your hands dirty, then abstract from experience – which will be capitalized on later.

As a first step towards obtaining better structuring of contents, we have introduced some guidelines for verbally stating objectives in the functional analysis process prior to learning so that they are expressed as achievements, thus commited to the spirit required by Melton for such analysis [1].

The next step consists of analyzing each atomic competence in its concepts and dexterities is carried out with the help of linguistic analysis to spot the required items: roughly, concepts are related to noun phrases and clauses, whereas dexterities are related to verb phrases. Often, competences as a whole appear as part of the context of another competence, for example, being able to use an oscilloscope to be able to measure a voltage with it.

Afterwards, both types of items pertaining to competences are classified into

- *new items* -concepts and dexterities specific to the unit in question-,
- and *prerequisite items*- concepts and dexterities required by the new items but introduced elsewhere.

The reason for this distinction is that requisite items define dependences on the new items they refer to which allow to build two different *dependence graphs* -one biased towards concepts and the other towards dexterities. These dependences between competences translate directly as dependences between the unit being analyzed and those where the requisite items are introduced (Figure 2). Thus, each graph directly expresses navigational constraints -either imposed by concepts or dexterities- as seen by the content developer -normally an educator- and as such are valuable knowledge which may ameliorate a drab or misleading learning sequence.

However, as expected, splitting contents into two such different types entails specializing reinforcement, self-assessment and enabling assessment materials both for concepts and for dexterities. But that matches well with current practice in engineering education where concept assessment and reinforcement- of a verbal nature and carried out through definitions or explanations- is clearly set apart from dexterity assessment and reinforcement -of an algebraic nature and normally instance- or problem-based.

III. Conveying Instructional Content with Computers

Computer-assisted education has turned out to be a key research and development area. The potential offered by computers as educational tools can be increased if time and distance barriers are torn down, offering students/trainees the possibility of using educational software whenever and wherever they want. Among the different techniques used in educational systems (intelligent tutoring, programmed teaching, etc.), hypermedia seems to be one of the most widely accepted [9]as it is a good form of representing human knowledge ([11], [10]). Indeed, as WWW technology, where both hypermedia and telecommunications converge, becomes increasingly mature and available to a wider range of users it begins to appear as a perfect environment for computer-assisted education.

However, accessibility is not enough to guarantee the usefulness of an educational system that should support different kinds of educational activities oriented towards aiding the acquisition of declarative and procedural knowledge [11]. Interactivity can be exploited to implement a great variety of expressive activities that propose students/trainees the challenge of using their knowledge and skills to solve practical and real problems whose need within educational systems has been repeatedly stated in the literature ([12], [13], [14]).

IV. An analysis of the special requirements for conveying contents with computers in an engineering subject

A. Selection of subject

Bearing in mind the above mentioned issues, we targeted an Electrical Engineering course content as candidate for "computerisation", spanning classical electrical network analysis and an introduction to circuit synthesis [8].

This subject affords incredible possibilities from the point of view of computer assistance ([4], [5], [6], [7]):

- a well-established theoretical domain (circuit theory) describable in mathematical terms,
- a visual description language of its own (circuit layouts and graph theory),
- and extensive collections of exercises for symbolic manipulation directly inspired in the theory.

All these facts guarantee that the content providing activity will be centred in adapting previously existing content (theory and exercises) to the new media rather than in rewriting the theory so that it can be conveyed easily to undergraduates under computer interaction. This allows us to insist on the pedagogical aspects.

Later, following the content development methodology, we obtained a hierarchical competence analysis for the main learning units. Care was taken, at this point, neither to express these competences through noun-phrases – which would have focused the competences on the concepts to be learnt -, nor active verb-phrases – which would have focused competences on the dexterities to be learnt – so that no learning bias would affect the navigation of the content.

B. Selection of material

However, we deemed the effort of developing simulation and symbolic manipulation-enabled content for the whole course too vast for a first approach, so we decided to concentrate in a particular unit describing the analysis of electrical two-ports. This particular subfield was chosen because:

- it has a richness of concept to allow non-trivial concept navigation;
- students should already have the full-fledged circuit theory at their disposal to be used for a number of exercises;
- two-ports have extensive applications in communications and electrical engineering, for example, as filters.

With the list of competences for a two-ports introductory unit, we excerpted all those exercises that covered the desired competences from a number of well-known textbooks ([4][5][6][7]). Interestingly enough, no single textbook covered all the different competences that were found important. So as to have a variety of approaches as wide as possible, no efforts were done to distinguish between purely symbolic or more practical exercises at first, but this later turned one of the main criteria for developing the exercises in their computerised form.

C. Use of tools

We then proceeded to review several well-known programs for circuit description, manipulation, simulation and visualization tools. Most of the candidates were obtained from a rapid skimming of the literature on computer-assisted electrical circuit teaching.

After discarding those that were propietary and considering also local availability and previous experience with it, we decided to use PSPICE as our main support tool – our university already had copies of it and it was being used in several other lab subjects, if not in a principled manner.

All selected exercises were attempted at with PSCPICE but some could not be carried through: although this tool allows simulation giving beautiful resolution frequency response of circuits, it does not give feedback in explicit form concerning the actual designs – deciding if they were fit for the purpose at hand -, so detecting students' misconceptions about the subject was impossible.

More to the point, as PSPICE lacks symbolic manipulation capabilities, we could not envision how the students' mathematical skills could be brought to bear into the learning interaction, nor how could their conceptions be elicited in symbolic form. Typically, a student would program his/her layouts and obtain numerical responses out of which they could not make sense and had no means to experiment with. However, this was not thought a shortcoming of the tool, but rather, of our understanding of its capabilities in using it as a teaching aid.

We thus estimated that another, complementary type of tool had to be used together with circuit simulation software, one which allowed symbolic mathematical manipulation.

Fortunately, MATLAB - a well-known general-purpose environment for vectorial calculus - is well-known to our students – mainly for signal processing purposes -, so we could profit by its restricted symbolic manipulation capabilities to try and overcome the shortcomings of simulation programs.

For all of the exercises that were not realisable in PSPICE we tried coding them in MATLAB. Interestingly enough, the set of exercises that were easily coded with MATLAB was almost disjoint with the set of exercises that were easily simulated with PSPICE. The cost of learning yet another library of MATLAB was thus balanced with the advantages in being able to use another approach to learning.

V. Conclusions

We set out to try and integrate into a methodology for developing highly interactive content - in the domain of electrical engineering, specifically -, some commercial, widespread engineering tools already known to our students. This was deemed necessary to guarantee modern instructional computer interaction as stated in [3].

Following the methodology, we analyzed the subject at hand and decided on a subset of the subject to test the ability of computers to convey it in the way we had devised.

Two tools were chosen to do the job, mainly because of their availability and the students' familiarity with them, but we found that none of the tools could nowadays support the kind of interactivity that we were aiming at separately, so that we resorted to combining their functionality by switching between them.

VI. Further Work

We are now studying how to seamlessly integrate all content-related devices – content development methodology, simulation system and symbolic mathematical tool - under a hypermedia browser, i.e. Netscape's Navigator, and will be using the scheme to conduct limited teaching experiences next year.

The foreseeable difficulties come on the part of integrating both tools, the simulator and the symbolic manipulator:
In spite of equations and layouts being different descriptions of the same underlying object (the electrical circuit) we will not be able to keep them synchronised, as both tools do not communicate easily, and we expect the student's understanding will be a bit baffled by this duplication.
Also, software development technicalities or licensing of the tools may prevent easy integration of the simulation and symbolic manipulation tool under a browser – the latter was true for MATLAB under Navigator which was attempted with another distance-education tool in a previous experience.
As in all other innovations in the teaching habits, we also foresee difficulties in engaging the students' collaboration in experimenting with new education-conveying and evaluation methods.

VII. Bibliography

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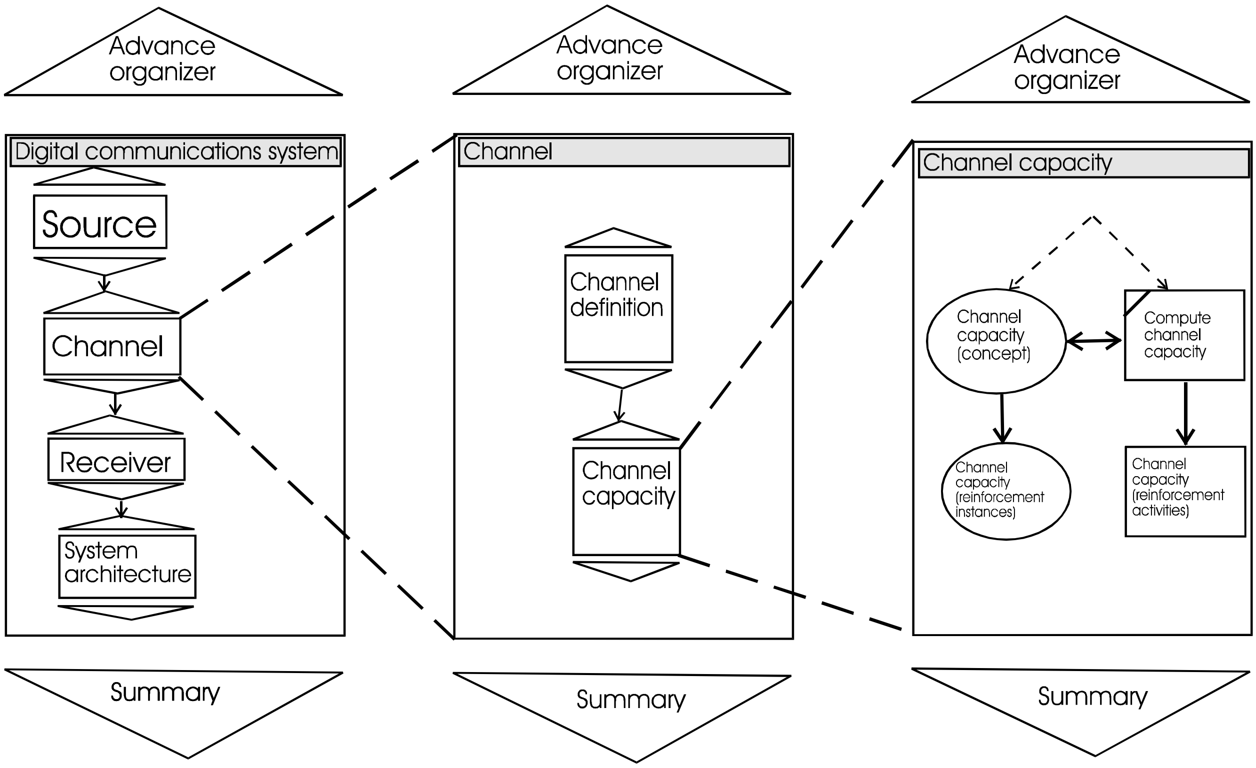

Figure 1: Hierarchical expansion of a study session.

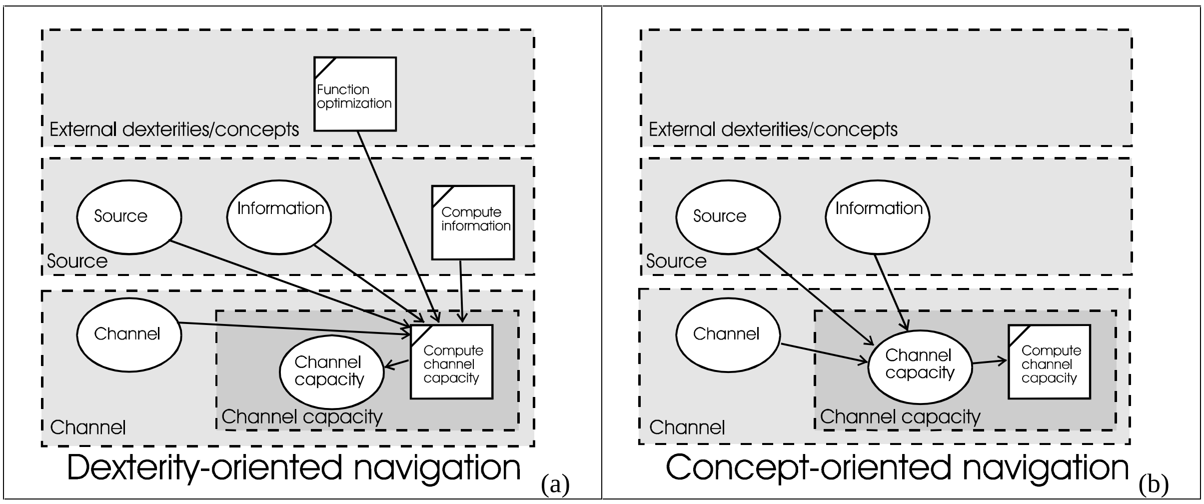

Figure 2: Dexterity- (a) and concept-biased (b) graphs.